§21. State Estimation of Superconducting Coil by Highly Utilization of Voltage and Acoustic Signal

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In the LHD superconducting system which is composed of a number of large superconducting coils, a high-performance state estimation system of a superconducting coil is essentially important. To obtain a highly reliable state estimation system, a traditional quench detection system monitoring only voltage signal itself would not be sufficient.

In such a situation, the authors have proposed to introduce a new estimation factor into the quench detection system. In order to improve the state estimation of superconducting coil, a utilization of voltage signal and acoustic signal would be effective. Unfortunately, in the LHD superconducting coils, any AE sensors are not attached. Therefore we concentrated our effort on the highly utilization of electric signals from the superconducting coil. Targeting more precise state estimation of H-I coil (Inner Helical coil), we introduced a new concept of the equivalent accumulated heat.

The equivalent accumulated heat W_{eff} is calculated by Equation (1).

$$W_{eff} = \int_0^T e^{-\frac{T-t}{\tau}} \cdot vi \cdot dt \qquad (1)$$

where, T: present time [s]

v: balance voltage [V]

i: coil current [A]

τ: heat dissipation time constant [s].

In an actual calculation, we accumulated discretely the heat generated in a period dt following Equation (2).

$$W_{eff} = \left\{ \begin{array}{l} V_1 \cdot e^{-\frac{n-1}{\tau}\Delta t} + V_2 e^{-\frac{n-2}{\tau}\Delta t} + \cdots \\ \cdots + V_{n-1} e^{-\frac{1}{\tau}\Delta t} + V_n \end{array} \right\} \times I \cdot \Delta t \qquad (2)$$

Where, $V_1, V_2, V_3 \cdots\cdots, V_n$ are the balance voltages at each sampling time. For the heat dissipation time constant τ, we applied the value 1 [s]. And, the sampling time Δt was selected to be 0.1 [s]. Meanwhile, we decided to consider the preceding heat until it decays lower than 1/100 of the initial value. So, from the condition $e^{-\frac{n-1}{\tau}\Delta t} < 0.01$, and $\Delta t = 0.1$, $\tau = 1$ [s], we obtain $n = 50$.

The calculated equivalent accumulated heat is used as the fourth input variable for the Fuzzy system in addition to the balance voltage, the current, and the liquid helium pressure. The calculated "dangerous rate" of the coil is displayed on a CRT as shown in Fig. 1.

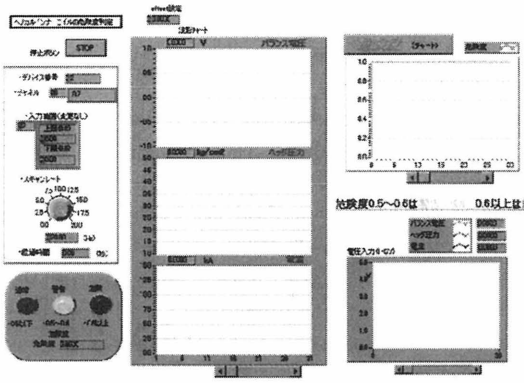

Fig. 1. CRT display of dangerous rate of superconducting coil.

The "dangerous rate" calculated introducing the equivalent accumulated heat is shown in Fig. 2, and, that in case of without it is shown in Fig. 3.

From these two figures, it can be understood that in case of introducing the equivalent accumulated heat the dangerous rate increases exceeding 0.5 (the alarm level) about 20 [s] earlier than in case of without it.

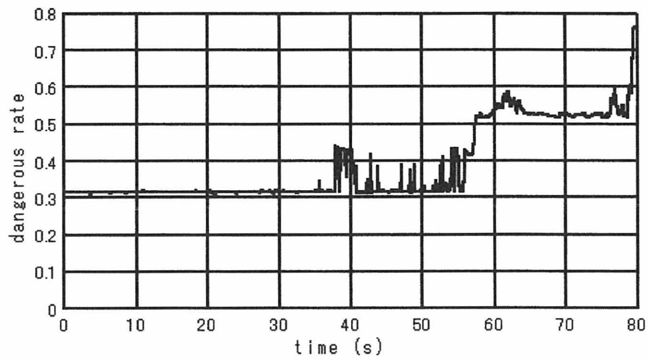

Fig. 2 Calculated dangerous rate in the new system introducing equivalent accumulated heat.

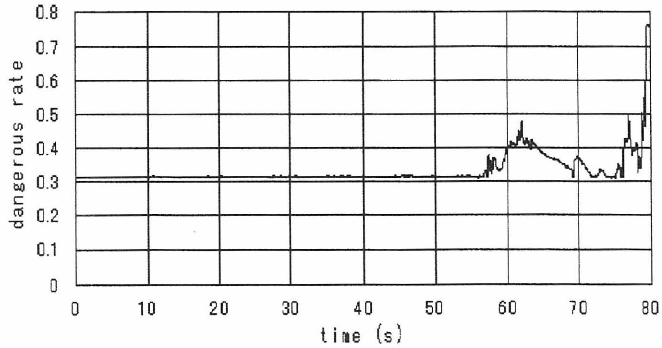

Fig. 3 Calculated dangerous rate in the old system without equivalent accumulated heat.